Analysis of Fuel Scheduling with Solar Sharing for Economic Dispatch using PSO

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***Abstract*—This paper deals with analysis of scheduling of solar sharing for fuel scheduling using particle swarm optimization (PSO). This multi-objective consider the minimization of fuel cost of thermal generating units with fuel scheduling and sharing of different photo-voltaic generating units to fulfill the load demand and fuel demand in such a way to minimize the total generating cost and satisfying all constraints using PSO technique. Now a days it is challenge to achieve reliable and inexpensive electricity in mature energy market. Exhaustion of fossil fuels reserves and rapid intensification of fuel price and increasing emission require the use of renewable energy sources in the energy market. In this paper, the test is carried out for 13 PV plants and 5 thermal units and solar constraints. Particle Swarm Optimization is used for optimization of the problem and simulation results have been computed in FORTRAN 90.**

Keywords—Fuel scheduling (FS), Economic Load Dispatch (ELD), Renewable Energy Sources, Photo-voltaic generating plants, Particle swarm optimization (PSO).

I. INTRODUCTION

To make reliable and inexpensive energy market, this paper presents analysis of scheduling of sharing of photo-voltaic generating units such as the commitment of photo-voltaic generating unit not only meet maximum generation at particular hours for economic dispatch but also saving of fuel using PSO. Now a day the generation of electricity is too expensive in terms of reliability. In recent days, only minimization of fuel cost of thermal generating units is not enough as due to increasing pollution [1], [2]. The rapid depletion of fuel energy reserves and environmental concerns has compelled us to incorporate the renewable energy resources in energy mix. The main objective of such system is to achieve the benefits of minimum production cost, saving of fuel, maximum reliability and better operating conditions.

Economic load dispatch problem is an optimization that allocates power to each generating units so as to minimize the total operational cost, subject to all constraints. In modern system only minimization of fuel cost is not enough but also saving of fuel so that the energy crises must be minimized and integrating with renewable energy generation system in present power system scenario. This objective function includes minimization of fuel cost of thermal generating units [15], minimization of solar cost with different scheduling at constant load [3].

Several classical optimization techniques such as Lambda-iteration method, gradient method, Newton's method, linear programming, Interior point method and dynamic programming have been used to solve the basic economic dispatch problem. Lambda iteration method has the difficulty of adjusting lambda for complex cost functions. Gradient methods suffer from the problem of convergence in the presence of inequality constraints. Newton's method is extremely sensitive to the selection of initial positions. Linear programming approach provides optimal results in less computational time but results are not accurate due to linearization of the problem. Interior point method is faster than linear programming but it may provide infeasible solution if the step size is not chosen properly. Dynamic programming suffers from curse of dimensionality. Therefore more of the classical optimization techniques need derivative information of the objective function to determine the search direction.

Recently, different heuristic approaches listed in literature have been proved to be effective with promising performance, such as evolutionary programming (EP) [4], simulated annealing (SA) [5], Tabu search (TS) [6], pattern search (PS) [7], Genetic algorithm (GA) [8], Differential evolution (DE) [9], Ant colony optimization [10], neural network [11] and PSO. Particle swarm optimization, an optimum global search technique provides effective and easier computational implementation with reduced memory requirement. PSO has greater global searching ability at the beginning of the run and has greater local search ability near the end of run [12].

In this paper, optimization of economic load dispatch problem including fuel scheduling with photovoltaic generating units using PSO is carried out. The test system is applied on 13 PV units and 5 thermal generating units considering fuel delivered and storage limit [15] and the data of Shilong where photovoltaic generating units are scheduled for different hours at constant load. The optimizations of the problem and simulation results have been computed in FORTRAN 90.

This paper is organized as follows: Section II describes the mathematical formulation of economic load dispatch including fuel scheduling problem using solar generating units. Section III presents a brief overview of Particle Swarm Optimization. In section IV the simulation is carried out for 13 PV generating units and 5 thermal generating units considering the fuel limit and result is discussed. In section V the conclusion is given showing the feasible solution of the problem and future work.

II. MATHEMATICAL FORMULATION OF FUEL SCHEDULING

This problem is associated with the power generating units having thermal and solar PV generations. Fuel scheduling economic dispatch problem is to determine the generated power of all on-line generating units which minimize the total fuel cost as well as consider fuel and storage constrains of the system, while satisfying equality and inequality constraints.

The fuel scheduling problem can be formulated as:

$$\mathrm{Min}F_T = \sum_{i=1}^{n}(F_i(P_i)) \quad (1)$$

where $F_T$combined objective function to be is minimized $F_c(P_i)$which represents fuel cost of i_{th} generating unit of ith generating unit.

The minimum fuel cost of ith unit is formulated as:

$$F_c(P_i) = a_iP_i^2 + b_iP_i + c_i + e_i \times \sin(f_i \times (P_{gi_{min.}} - P_{gi}))\frac{\$}{h} \quad (2)$$

Subject to:

a) Equality constraints

$$((\sum_{i=1}^{n} P_{g_i}) - P_L - P_D = 0 \quad (3)$$

where P_{g_i} is generated power by ith unit, P_L represent power loss, $P_D$is power demand and n is total number of generating units.

The power losses are calculated as:

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{g_i}B_{ij}P_j \quad (4)$$

where B is loss coefficient matrix.

Fuel delivery constraints

$$((\sum_{i=1}^{n} F_{g_i}) - F_D = 0 \quad (5)$$

where F_{g_i} is fuel delivered to ith unit, $F_D$is fuel demand and n is total number of generating units.

$$V_i = Vin_i - t * (\alpha_iP_i^2 + y_iP_i + b_i) \quad (6)$$

where V is fuel storage to ith unit, t is time interval.

b) Inequality constraints:

$$P_{gi_{min.}} \le P_{gi} \le P_{gi_{max}} \quad (7)$$

Where $P_{gi_{min.}}$and $P_{gi_{max}}$ are minimum and maximum generating power limits of ith generating units.

$$F_{gi_{min.}} \le F_{gi} \le F_{gi_{max}} \quad (8)$$

Where $F_{gi_{min.}}$and $F_{gi_{max}}$ are minimum and maximum fuel delivered limits of ith generating units.

$$V_{gi_{min.}} \le V_{gi} \le V_{gi_{max}} \quad (9)$$

Where $V_{gi_{min.}}$and $V_{gi_{max}}$ are minimum and maximum fuel storage limits of ith generating units.

The economic dispatch problem is formulated by combining fuel cost functions by implementing penalty.

$$\mathrm{Min}F_c = \sum_{i=0}^{n}(a_iP_i^2 + b_iP_i + c_i + e_i \times \sin(f_i \times (P_{gi_{min.}} - P_{gi})\ \$/h \quad (10)$$

The power generated by solar plant is calculated as:

$$P_{gs} = P_r\{1 + (T_{ref} - T_{amb}) \times \alpha\} \times \frac{S_i}{1000} \quad (11)$$

where $P_r$is its rated power, T_{ref} is the reference temperature, T_{amb} is the ambient temperature, $\alpha$is temperature coefficient and S_i is the incident solar radiation.

The solar share is calculated from generating units taking part in the dispatch:

$$E_{ss} = \sum_{j=1}^{m} P_{gs_j} \times U_{s_j} \quad (12)$$

Where P_{gs_j} power is available from jth solar plant and U_{s_j} represents the status of jth power plant in operating or non-operating zone.

The Solar power cost is formulated as:

$$F_{sc} = \sum_{j=1}^{m} E_{pu_j} \times P_{gs_j} \times U_{s_j} \quad (13)$$

where E_{pu_j} is per unit cost of jth solar power plant.

When we combine the single objective function of solar share and total available solar power in order to achieve the maximum benefit of solar availability, the combined objective function is formulated along with cost minimization given as:

$$\mathrm{Min}F_T = F_i(P_i) + E_i(P_i) + F_{sc} \quad (14)$$

Subject to:

$$P_D + P_L - \sum_{i=1}^{n} P_{gi} - \sum_{j=1}^{m} P_{gs_j} * U_{s_j} = 0 (12)$$

$$P_{gi_{min.}} \le P_{gi} \le P_{gi_{max}} \quad (15)$$

$$\forall U_{s_j} \in \{0,1\} \quad (16)$$

III. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is an optimization technique which basically depends on social behavior like bird flocking and fish schooling. According to the global variant, each particle moves towards its best previous position and towards the best particle in the whole swarm. On the other hand, in the local variant, each particle moves towards its best previous position and towards the best particle in its restricted neighborhood. The position and velocity vectors of the i^{th}particle of a d-dimensional search space can be represented as: $P_i = (P_{i1}, P_{i2}, P_{i3}, \dots, P_{id})and\mu_i = (\mu_{i1}, \mu_{i2}, \mu_{i3}, \dots, \mu_{id})$. The best previous position of a particle is represented as$P_{best} = (P_{i1}, P_{i2}, P_{i3}, \dots, P_{id})$. A constant$V_{max}$, is used to arbitrarily limit the velocities of the particles and improve the resolution of the search. After applying inertia weight factor the updated velocity equation is represented as:

$$\mu_{i,j}^{k+1} = w * \mu_{i,j}^{k} + C_1 \times \mathrm{rand}() \times (P_{i,j}^{best} - P_{i,j}^{k}) + C_2 \times \mathrm{rand}() \times (G_j^{best} - P_{i,j}^{k}) \quad (17)$$

$$P_{i,j}^{k+1} = \mu_{i,j}^{k+1} + P_{i,j}^{k} \quad (18)$$

Where i = 1,2,3 ... m is number of particles, j = 1,2,3 ... n is number of members in particle, k = 1,2,3 ... iter

Inertia weight is modified each iteration and is expressed as a modified equation:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \quad (19)$$

where w_{max} maximum value of inertia is weight and w_{min} is minimum value of inertia weight. $iter_{max}$is maximum number of iterations. Eberhart and Shi [14] indicates that the optimal strategy is to initially set w to 0.9 and reduce it linearly to 0.4, allowing initial exploration followed by acceleration toward an improved global optimum.

IV. RESULTS AND DISCUSSION

The simulation is carried out for 13 PV generating units and 5 thermal generating units with considering the fuel demand and storage limit. PSO is implemented for solving this problem at different load but load is constant at different hours for same radiation data. Sharing of photovoltaic generating units for day at load of 700 MW, 800MW, 650MW with different solar committing units shown in table [4,5,6]. Data of solar radiation of Shilong of 14 June 2014 is shown in table[3].

Now the simulation is carried out at different load 800MW, 650MW and results are shown in table [7]. The effect of inclusion of solar power in our problem at different load shows that with increasing in solar radiation, the solar sharing increases and at same time fuel use is reduced in thermal generating unit.

TABLE-1: POWER RATING AND OR UNIT COST OF PV GENERATING UNITS [1]

Units	Prated (MW)	Unit rate ($/KW h)
1	20	0.22
2	25	0.23
3	25	0.23
4	30	0.24
5	30	0.24
6	35	0.25
7	35	0.26
8	40	0.27
9	40	0.27
10	40	0.275
11	40	0.28
12	40	0.28
13	40	0.28

Table1 give the rated power of 13 PV generating units and unit rate of each PV unit. Table [2] give the fuel demand and load for a given time interval. In this paper solar generation calculate each hour and then take average of power generation from the PV generating unit. The remaining demand is satisfied by thermal unit.

The commitment of PV generating unit for cost effective and increase the storage of fuel and less effect on environment. Table 5 shows scheduling of PV plant for 700MW load and 7000 fuel demand. In this solar radiation is highest from 11:00-3:00PM there is maximum generation from solar units and minimum at morning and evening. To calculate the effect on fuel scheduling power from PV units taking as average in first case average is 38 MW. Cost from thermal units is 1934 $/h and solar cost is 235152.800 $/h. same is for time interval 168 hours.

The commitment of PV generating unit for cost effective and increase the storage of fuel and less effect on environment. Table 6 shows scheduling of PV plant for 650MW load and 7000 fuel demand. To calculate the effect on fuel scheduling power from PV units taking as average in first case average is 36MW. Cost from thermal units is 1906.7 $/h and solar cost is 227393$/h. same is for time interval 168 hours.

Table 4 shows scheduling of PV plant for 800MW load and 7000 fuel demand. In this solar radiation is highest from 11:00-3:00PM there is maximum generation from solar units and minimum at morning and evening. To calculate the effect on fuel scheduling power from PV units taking as average in first case average is 40MW. Cost from thermal units is 2242 $/h and solar cost is 245112.800$/h. same is for time interval 168 hours.

Table-2: Load demand and fuel delivered during scheduling period [15]

No.	Duration (h)	Load (MW)	Fuel delivered (ton)
1	168	700	7000
2	168	800	7000
3	168	650	7000

Table-3: solar radiation and temperature for 14th day of 2014 june

Time	Global solar radiation (W/m2)	Temperature (℃)
1:00	0	30
2:00	0	29
3:00	0	28
4:00	5	28
5:00	43.33	28
6:00	131.66	26
7:00	315	29
8:00	190	31
9:00	350	33
10:00	360	34
11:00	541.66	35
12:00	651.667	36
13:00	783.33	37
14:00	755	37
15:00	631.55	37
16:00	451.33	38
17:00	48.33	38
18:00	13.33	37
19:00	0	35
20:00	0	34
21:00	0	34
22:00	0	33
23:00	0	32
0:00	0	30

Table-4: Sharing of thermal and PV generating units at second interval

Time	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:0**	**12:0**	**13:0**	**14:0**	**15:0**	**16:0**	**17:0**
1	1	0	0	0	1	0	0	0	1	1	1	0	0	1
2	0	1	1	0	1	1	1	0	1	1	1	0	0	1
3	1	1	0	1	0	1	0	1	1	0	1	0	1	1
4	1	1	1	0	0	1	1	1	0	1	1	0	0	1
5	0	1	0	0	0	0	1	1	1	1	0	1	1	0
6	0	0	0	0	1	1	1	0	1	0	1	1	0	0
7	0	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	0	1	0	1	1	1	1	0	1	0	1	0	1
9	1	1	1	1	1	1	0	1	0	1	1	1	1	1
10	0	1	1	1	0	0	0	1	1	0	1	1	1	1
11	0	1	1	1	1	0	0	0	1	0	1	1	1	0
12	1	0	0	0	1	0	1	0	1	1	1	1	1	1
13	0	0	0	0	0	1	1	0	1	1	1	1	1	0

Table-5: Sharing of thermal and PV generating units at first interval

Time	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:0**	**12:0**	**13:0**	**14:0**	**15:0**	**16:0**	**17:0**
1	1	0	0	0	0	0	0	1	1	0	1	0	1	1
2	1	1	1	1	1	1	0	0	1	1	0	1	1	1
3	0	1	1	0	1	1	1	0	1	1	1	1	0	1
4	1	1	0	0	0	0	1	0	1	1	0	1	0	0
5	0	1	0	0	1	1	0	0	1	1	1	1	0	0
6	0	1	0	1	1	1	0	1	1	1	0	1	0	1
7	0	1	0	0	1	1	1	1	0	1	0	0	1	1
8	0	1	1	0	1	1	1	1	0	1	0	0	0	1
9	1	1	0	1	1	1	1	1	1	1	0	1	1	1
10	0	1	1	1	1	1	1	1	1	0	0	0	1	0
11	0	0	0	0	1	1	1	1	0	0	0	0	0	1
12	1	0	1	0	1	1	1	0	0	1	0	1	0	0
13	0	0	1	1	0	1	1	1	0	0	1	0	1	1

Table-6: Sharing of thermal and PV generating units at third interval

Time	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:0**	**12:0**	**13:0**	**14:0**	**15:0**	**16:0**	**17:0**
1	0	1	1	0	1	0	0	0	1	0	0	1	0	1
2	0	1	0	0	0	0	0	0	1	0	1	1	1	1
3	0	1	1	0	1	1	1	0	0	0	0	0	1	0
4	0	1	0	0	1	0	1	0	1	1	1	1	1	0
5	1	1	1	0	1	1	1	0	1	1	1	1	0	1
6	1	0	1	1	0	1	0	0	1	1	0	0	1	0
7	0	0	1	1	1	1	1	0	0	1	1	1	1	0
8	1	0	1	1	1	1	1	1	1	1	1	0	0	0
9	1	0	0	1	1	0	1	1	1	0	1	1	0	0
10	0	0	1	1	1	1	1	1	1	1	1	1	0	1
11	1	1	1	0	1	0	1	1	0	1	1	0	1	1
12	1	0	0	1	0	1	0	1	1	1	1	1	1	0
13	0	0	0	1	0	1	1	1	1	0	0	1	1	0

Table-7: Cost of thermal and solar & emission at different hours for different loads

Time	**1**		**2**		**3**	
No.	**Power (MW)**	**Fuel delivered (ton)**	**Power (MW)**	**Fuel delivered (ton)**	**Power (MW)**	**Fuel delivered (ton)**
1	42.92	1000	37.47	728	31.1	1000
2	108.89	1000	125	1000	122.1	1000
3	174.99	2000	175	2000	175	2000
4	40	3000	133.47	2400	40	3000
5	295.13	0	288.817	872	245.36	0
Solar power	38.043		40.22	245112.400	36.55833	227393.2
Cost	1934.519*168		2242.552*168		1906.03*168	

Table-8: Cost coefficients and limits of thermal generating unit [15]

No	**a**	**b**	**c**	**d**	**e**	**Pmin**	**Pmax**	**Fmin**	**Fmax**	**Vmin**	**Vmax**	**α**	**β**	**γ**
1	0.008	2	25	10	.012	20	75	0	1000	0	10000	.83612	.066889	.000026756
2	0.003	1.8	60	20	.01	20	125	0	1000	0	10000	2.00669	.0602	.000010033
3	0.0012	2.1	100	30	.009	30	175	0	2000	0	20000	3.34448	.07023	.00004013
4	0.004	2.2	120	40	.008	40	250	0	3000	0	30000	4.01338	.0753578	.000013378
5	0.0015	1.8	40	50	.007	50	300	0	3000	0	30000	1.33779	.0602	.000005017

V. CONCLUSION

In this paper, Particle swarm optimization technique is used to solve fuel scheduling with solar sharing problem. The purpose of using fuel scheduling problem including solar and thermal generating units taking average of solar generation at different hours for given load is to fulfill the increasing demand with satisfying the condition of exhaustion of fossil fuels and increasing the storage. This method is computed with environmental and economical conditions simultaneously using maximum PV generating units at different hours with scheduling for obtaining maximum power generation for the data given in Table 1.The results demonstrate better results in terms of minimum emission and minimum total cost for this problem with less computational time and more accurate global best solution.

REFERENCES

1. N. A. Khan, "Combined Emission Economic Dispatch of power system including solar photo voltaic generation" Energy Conversion and management, (92) pp. 82-91, 2015.
2. H. Hamedi, "Solving the combined economic load and emission dispatch problems using new heuristic algorithm", Electrical Power and Energy Systems (46) pp. 10–16, 2013.
3. S Brini, HH Abdullah, A. Ouali, "Economic dispatch for power system included wind and solar thermal energy", Leonardo J Sci; 14:204–20, 2009.
4. Nagendra Singh, Y. Kumar, "Economic Load Dispatch with Environmental Emission Using MRPSO" , In Proceedings of IEEE Conference on Advance Computing , pp. 995-999, 2013.
5. K.Y. Lee, S.Y. Arthit, "Adaptive Hopfield neural network for economic" , IEEE Trans. Power Syst. Pp. 519–26, 1998.
6. D Jeyakumar, T Jayabarathi, T. Raghunathan, "Particle swarm optimization for various types of economic dispatch problems." International Journal of Electrical Power Energy System, 28(1):36–42, 2006.
7. Y-M. Park, W. Jong-Ryul, P. Jong-Bae, "A new approach to economic load dispatch based on improved evolutionary programming", Eng. Intell. Syst. Elect. Eng. Commu. Vol. 6 pp. 103–110, Jun. 1998.
8. Kennedy J., "Particle swarm optimization", Encyclopedia Mach Learn, pp. 760–766, 2010.
9. A.I.S. Kumar, K Dhanushkodi, J JayaKumar, C. K. C. Paul, "Particle swarm optimization solution to emission and economic dispatch problem", In proceedings of Conference on convergent technologies for the Asia-Pacific region, 2003.
10. Y. Sonmez, "Multi-objective environmental/economic dispatch solution with penalty factor using Artificial Bee Colony algorithm.", Sci Res Essays , Vol. 6 pp. 2824–2831, 2011.
11. A. El Desouky, "Security and stochastic economic dispatch of power system including wind and solar resources with environmental consideration", International Journal of Renewable Energy Resources, Vol. 3 , pp. 951–958, 2013.
12. DM Emmanuel, AO. Nicodemus, "Combined economic and emission dispatch solution using ABC_PSO hybrid algorithm with valve point loading effect", International Journal Sci Res Publication, Vol. 2, pp. 1–9, 2012.
13. F Yao, K Meng, Z Xu, ZY Dong, H Iu, JH Zhao, "Differential evolution algorithm for multi-objective economic load dispatch considering minimum emission costs" In: Power and energy society general meeting; pp. 1–5, 2011.
14. MS Osman, MA Abo-Sinnab, AA Mousa, "An e-dominance-based multiobjective genetic algorithm for economic emission load dispatch optimization problem", Electrical Power System Res; vol. 79 pp. 1561–1567, 2009.
15. Basu, M. "Group search optimization for economic fuel scheduling" *International Journal of Electrical Power And Energy Systems*, Vol. 64,pp. 894-901, 2015.